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(54) **Femur head centre localization**

(57) The invention relates to a method for localizing the femur head centre (FHC) using only a tibia marker array (TM) attached to the tibia (T), wherein the knee is considered to be a joint having two degrees of freedom, the tibia (T) is brought to a position which restricts one degree of movement of the knee joint (KJ) so that the knee joint (KJ) has basically only a single degree of freedom, the knee is moved by moving the femur (F) and/or the tibia (T) and a distance di is calculated so that the lines of movement of a point (FHC) having the distance di from the knee joint (KJ) coincide in a single point which is considered to be the femur head centre (FHC). Furthermore, the invention relates to and an apparatus for localizing the femur head centre (FHC) using a tibia marker array (TM) connected to the tibia (T), comprising a camera (C) for localizing the tibia marker array (TM), a computer (PC) connected to the camera (C) to obtain the positional data of the tibia marker array (TM) from the camera images of the tibia marker array (TM) and a database (Data) storing a kinematic model of the knee joint (KJ) having two degrees of freedom, which database (Data) is connected to the computer (PC) which calculates a distance di so that the lines of movement of a point (FHC) having a distance di from the knee joint (KJ) coincides in a single point which is considered to be the femur head centre (FHC).

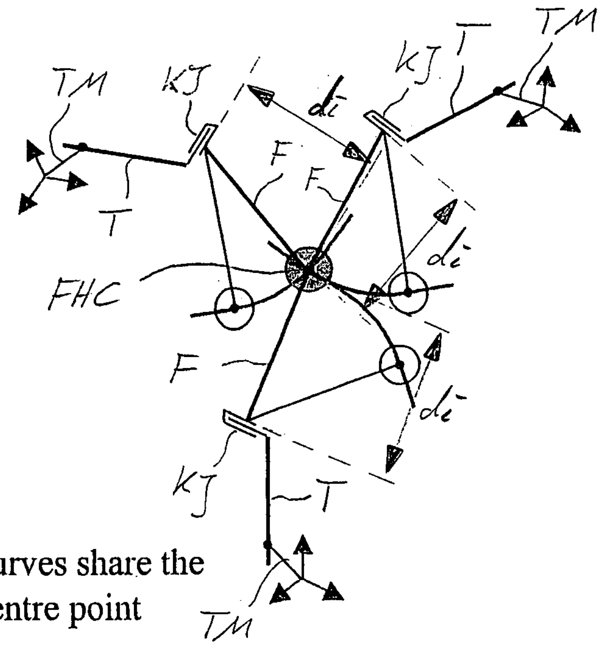

Fig. 3d: Curves share the real centre point

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Description

[0001] The present invention concerns a method and an apparatus for determining the femur head centre location without a femur marker array.

[0002] Usually a femur marker array and a tibia marker array are used to determine the position of the femur, especially the femur head centre and the tibia, if surgical procedures at the knee are conducted.

[0003] It is an object of the invention to determine or define the location of the femur head centre while improving the accessibility of the knee joint and to reduce invasiveness.

[0004] This object is solved by a method and an apparatus according to the independent claims. Preferred embodiments are defined in the dependent claims.

[0005] According to the invention, the location of the femur head centre is determined by using a tibia marker array only which can also be used for subsequent navigation purposes on tibia or femur.

[0006] A three-step approach including calibration, attachment and reproduction can be used for the present invention.

Calibration

[0007] As shown in Figure 1a, a kinematical model of the leg including the femur centre of rotation is determined by using a tibia marker array TM attached to the patient's leg L and moving the leg L to different positions during a calibration procedure. The marker array TM can be either fixed directly to the tibia or can be fixed to the leg using e.g. a Velcro ® without performing any surgical steps.

Attachment

[0008] The determined femur centre of rotation position is virtually connected to the tibia marker array TM to describe its position for a specific user-defined position of the patient's leg, as e.g. for a specific flexion as shown in Figure 1b. This can be sufficient for navigated surgical steps on the tibia alone, which just rely on the femur head position in a specific knee position, as described below as "tibia-only workflow". For example, the proximal tibia cut could be aligned to the femur mechanical axis established in 90° flexion of the knee joint.

Reproduction

[0009] For later reproduction after patient movements, the initially found centre position is transformed to camera space by reproducing the initially user-defined leg position and capturing the corresponding tibia marker position with the camera system, as shown in Figure 2c.

[0010] The invention simplifies the knee joint kinematics to a mechanical model with few, e.g. two or in a specific defined position of the tibia relative to the knee or the femur only one fixed rotational degrees of freedom. A possible concept amongst others is a model with two rotational degree of freedom, as shown in Figure 3a. A hinge is being used to describe knee flexion and another one is being used to describe tibia rotation within the knee joint KJ. The femur head centre FHC sits at the end of a link attached to the flexion axis. The tibia marker array TM sits at the end of a link attached to the rotation axis. These rotational axes form a simplified mechanical model of the knee joint KJ. Their positions and orientations with respect to each other and the marker array TM are the mechanical parameters of the model. In the simplest possible example configuration, both rotational axes are orthogonal and the femoral head centre FHC moves on a regular sphere with respect to the tibia T, as shown in Figures 3a and b.

[0011] For a specific patient with a marker array TM attached to the tibia T in a specific position, the model parameters are unknown before calibration. After calibration they can be calculated.

Calibration

[0012] Calibration is carried out with rotational and translational movements of the tibia T and the femur F around the femur head centre FHC located in the pelvis, as shown in Figure 1a. The centre point itself is kept still in space while the leg is being moved and the knee is being bent during the calibration run.

[0013] The orientations and the locations of the two rotational axes of the knee joint hinges are being derived from a data set of positions of the tibia array acquired with the camera system. Furthermore, the location of the femur head centre is being calculated with respect to the flexion hinge. With these parameters, the mechanical model is defined and can describe the possible locations of the femoral head centre FHC in dependency to the current flexion and internal rotation angles applied to the hinges.

[0014] The calibration procedure utilizes the fact, that the parameters of the model except for the flexion and rotation angles must be the same for all acquired tibia positions during the calibration run. Furthermore, the femur head centre position with respect to the camera coordinate system keeps still during the tibia movements. If the mechanical model is applied to describe the possible femur head centre points for all of the recorded tibia array positions, there must be a common point in camera space contained by all of the models. This common point in camera spare is the femur head centre point FHC, as shown in Figure 3d. The calibration algorithm varies the mechanical parameters to establish this common point with minimum error. Thus, a distance di (or "a" according to the Denavit-Hartenberg notation) of the femur head centre FHC from the simplified knee joint KJ is calculated so that a single point of intersection is found. For distances larger or smaller than di there could be more points of intersection.

[0015] In general the knee or one or more joint elements of a body can be modelled as a kinematical chain which can be moved to determine the parameters describing the model to obtain finally the location of the centre of rotation of one end element of the chain being kept fixed while using and tracking the movements of only a single marker or reference array connected to an opposite end element of the kinematical chain.

[0016] Biomechanical literature describing the behaviour of the physiological knee joint support the idea of a hinge kinematic under certain circumstances. Hassenpflug J: "Gekoppelte Knieendoprothesen" describes in Der Orthopäde 6 (2003) 32, S.484-489 that under external rotation the orientation of the flexion axis keeps fixed over a certain flexion range (mono-centric behaviour). Thus the knee joint degenerates to a single flexion hinge (external rotation stays fixed to a constant value), see Fig. 4a and 4b. Wetz H. et al.: "Die Bedeutung des dreidimensionalen Bewegungsablaufes des Femurotibialgelenks für die Ausrichtung von Knieführungsorthesen" in Der Orthopäde 4 (2001) 30, S. 196-207 supports the idea of simplifying knee kinematics to a flexion hinge in the flexion range of about 25° to 90° with his own findings about the location of the knee axes.

[0017] The reported physiological behaviour can be used to simplify the mechanical model within the invention even further by skipping the second hinge used for internal respective external rotation, see Figure 3c. To achieve this, the tibia can be rotated to a specific location or position where further rotation of the tibia T is restricted or limited wherein the tibia is held in this position to relative to the femur or knee during further movement of the leg. For maximum computing stability, calibration should then be conducted in the range of 30 to 90° flexion and concomitant maximum external respective internal rotation by the surgeon.

<u>Attachment</u>

[0018] After calibration, the femur head centre location is defined within the kinematical model. Its position and orientation with respect to the tibia marker array TM is then computed for the user-defined current stance and virtually attached by means of a calculated transformation matrix to the tibia marker array TM, see Figures 1b and 2b. This transformation is valid for the current stance. It can now be exploited for alignment purposes on the tibia, as described below in Example I.

[0019] To enable later reproduction, the initial stance should be one with a mechanically reproducible femur centre position with respect to the tibia, as e.g. full extension paired with high external rotation, as described below. Thus, it keeps valid with respect to the tibia array despite of any camera or patient movements.

[0020] Hassenpflug 1. c. shows, that the knee joint has a certain freedom for internal respective external rotation dependent on the current flexion angle, see Fig. 4a and 4b. This freedom is minimized in full extension to a range of +/- 8°. Attachment can thus be carried out e.g. in full extension and maximum external rotation (8°) to exploit this point of limit-stop as a reproducible stance. Given that no intermediate surgical steps have changed the kinematics of the joint, this stance can be reapplied at any time.

<u>Reproduction</u>

[0021] Surgical steps on the femur rely on the current femur head centre position with respect to camera space. Before such a surgical step is being navigated, the femur head centre must be reproduced in camera space, see Figure 2c. After having positioned the leg in the reproducible stance, the position of the tibia marker array TM is being read form the camera system C and the known transformation matrix is being applied to calculate the current centre position in camera space. As long as the patient’s hip is not being moved, the femoral head centre FHC can be used for navigation. Since typical navigation steps, as e.g. aligning a drill guide, can be carried out rather quick, the hip centre can be kept still for such short periods.

[0022] Thus, according to the invention, a femur marker array can be omitted to minimize trauma on the femur and to improve accessibility of the limited space within the knee joint during surgery, which is particularly useful for minimal invasive or time-critical surgical procedures.

[0023] Avoiding a femur marker is highly valuable for minimal invasive surgical procedures such as uni-compartmental knee procedures, where a marker array on the femur cannot be attached because of limited space or time.

[0024] Although the precision of the described approach can be limited, i.e. by the quality of the mechanical knee model used for calibration, it is beneficial for procedures where less precision for the femur head is sufficient and at the same time the application of a femoral marker array is not possible or desired. Such conditions apply to specific surgical procedures, e.g. for the Oxford uni-compartmental implant family due to its spherical constructions and the minimally invasive nature of the procedure.

[0025] The invention will be described with reference to the drawings which show in

Figures 1a to 1c	the calibration, attachment and tibia navigation in a tibia-only procedure;
Figures 2a to 2d	the calibration, attachment, reproduction after movement and femur navigation of a femur-too procedure;
Figures 3a to 3b	the calculation of the femur head centre according to the present invention;
Figures 4a and 4b	the rotational behaviour of the knee joint according to Hassenpflug; and
Figures 5a and 5b	models of the knee having one and two degrees of freedom, respectively.

Example I

[0026] A tibia-only workflow for unicompartmental surgery using the present invention is described with reference to Figure 1.

[0027] Two tibial cuts are applied without navigating any femur surgical steps, wherein the alignment of these tibial cuts depends on the position of the femur head centre in 90° knee flexion. According to the invention, this alignment can be achieved without using a femoral marker array and without time consuming femoral registration.

[0028] After moving the knee during the calibration run, the calculated femur head centre is "attached" to the tibia maker array in a fixed position, as e.g. a 90° flexion position, and relaxed external rotation state of the knee.

[0029] The flexion angle can be adjusted to 90° before attaching the femur head centre point. This can be supported by navigation without using a femoral marker array by simply connecting a line from the known femur head centre point to the femoral notch. This point can be acquired with a pointer with the knee flexed in approximately 90° flexion. It is virtually attached to the tibia array to be tracked on further movements. When the knee is brought in such a position, that the line is orthogonal to the known tibia mechanical axis, the amount of flexion is nearly 90°. In this state, the position of the femur head centre defined in camera space is being virtually attached to the tibia marker array and the tibia cuts are subsequently being navigated.

[0030] This 90° flexion position is well suited especially for the subsequent vertical tibia cut, because it has to point to the femur head in 90° flexion of the knee. The cut can be subsequently navigated despite any simultaneous camera or patient movement, because the relevant femur centre point is virtually attached to the tibia marker array.

Example II

[0031] A femur-too workflow in Oxford unicompartmental surgery is described with reference to Figure 2.

[0032] Besides tibia cuts also femur cuts are being performed. A femoral drill guide is navigated to geometrically define the location of the femur implant.

[0033] The rotational alignment of the drill guide is defined in Varus-Valgus and in Flexion-Extension with respect to the femoral mechanical axis, which is defined by the femur head centre point and a notch point on the proximal femur. With the invention, the drill guide alignment can be achieved without using a femoral marker array and without femoral registration.

[0034] After calibration, the calculated femur head centre is attached to the tibia marker array after calibration in full extension and maximum external rotation applied by the surgeon. This leg position is reproducible, because any rotational freedom of the knee is locked. From this point on, surgical steps causing movements of the patient or the leg may occur. Just before the drill guide shall be navigated, the full extension stance is being re-applied to the knee by the surgeon and the tibia marker array is being captured by the camera. Then the femur head centre position defined with respect to the tibia array is transformed into camera space. Subsequent navigation of the drill guide is done in camera space with respect to the known femur head centre and the tracked tibia marker array. The leg can be brought into any convenient position for the drill guide navigation step as long as the femur head is being kept in a fixed position. Note, that unlike to the tibia-only-workflow described in Example I, any camera moves must be impeded for the time of the drill guide navigation.

[0035] Figure 5a shows a model of a knee joint having one degree of freedom.

[0036] A single or primitive joint element is a basic or elementary joint and can e.g. be described according to the notation of Denavit-Hartenberg by the parameters s, a, α and d, wherein s and a represent translations and α and d represent a rotation.

[0037] The reference array attached to the tibia T is represented by a coordinate system 0 with the axes x_0, y_0 and z_0. The parameters s_0, d_0, a_0, α_0, s_1, d_1, a_1 and α_1 describe the geometric model, wherein parameter d_1 represents the flexion of the knee joint.

[0038] The translation of the coordinate system 0 along its z-axis z_0 by the amount of s_0, the subsequent rotation around z_0 by d_0, the subsequent translation by a_0 along the now rotated x-axis and the subsequent rotation around the rotated x-axis by α_0 yields coordinate system 1 with the coordinate axes x_1, y_1 and z_1.

[0039] Translation of coordinate system 1 along z_1 by amount s_1, subsequent rotation around z_1 by d_1, subsequent translation by a_1 along the now rotated x-axis, subsequent rotation around the rotated x-axis by α_1 yields coordinate system 2 with the axes x_2, y_2, z_2.

[0040] The origin of coordinate system 2 sits in the centre of rotation inside the femur head.

[0041] The acquisition of marker positions is a prerequisite to determine the model parameters and is performed as follows:

1. Extend the knee fully and apply maximum internal respectively external rotation to the knee in order to lock rotation. With the tibia reference array attached, conduct circular movements around the femur centre of rotation.
2. Allow flexion in the knee joint up to 30° to 40° and repeat step 1 several times with changed flexion.
3. Vary adduction respectively abduction in the hip joint and repeat step 2 several times with changed adduction respectively abduction. Always keep the rotation of the knee joint locked.

[0042] Figure 5b shows a model of the knee having two degrees of freedom.

[0043] As for figure 5a, the reference array attached to the tibia is represented by a coordinate system 0 with the axes x_0, y_0 and z_0.

[0044] The translation of coordinate system 0 along its z-axis z_0 by amount s_0, subsequent rotation around z_0, by d_0, subsequent translation by a_0 along the now rotated x-axis and subsequent rotation around the rotated x-axis by α_0 yields coordinate system 1 with the axes x_1, y_1 and z_1.

[0045] The translation of coordinate system 1 along z_1 by amount s_1, subsequent rotation around z_1 by d_1, subsequent translation by a_1 along the now rotated x-axis, and subsequent rotation around the rotated x-axis by α_1 yields coordinate system 2 with the axes x_2, y_2, and z_2.

[0046] The translation of coordinate system 2 along z_2 by amount s_2, subsequent rotation around z_2 by d_2, subsequent translation by a_2 along the now rotated x-axis, subsequent rotation around the rotated x-axis by α_2 yields coordinate system 3 with the axes x_3, y_3 and z_3.

[0047] The origin of coordinate system 3 sits in the centre of rotation inside the femur head. The parameters s_0, d_0, a_0, α_0, s_1, d_1, a_1, α_1, s_2, d_2, a_2 and α_2 describe the geometric model. Parameter d_1 represents the internal respectively external rotation and parameter d_2 the flexion of the knee joint.

[0048] To model the complex behaviour of the knee joint more adequately and in order to gain precision, it may be enhanced by introducing further sets of s, d, a, and α parameters for further degrees of freedom.

[0049] The acquisition of marker positions as prerequisite to determine the model parameters is performed as follows:

1. Extend the knee fully and apply maximum internal respectively external rotation to the knee in order to lock rotation. With the tibia reference array attached, conduct circular movements around the femur centre of rotation.

2. Allow flexion in the knee joint up to 30° to 40° and repeat step 1 several times with changed flexion. Release the locked rotation and constantly change the rotation within its physiological range.

3. Vary adduction respectively abduction in the hip joint and repeat step 2 several times with changed adduction respectively abduction.

Claims

1. Method for localizing the femur head centre (FHC) using only a marker array (TM) attached to the tibia (T), wherein the knee is considered to be a joint having one, two or more degrees of freedom whose kinematical behaviour is modelled with primitive joint elements and a geometrical description of the position and orientation of the primitive joint elements, a range of motion of the tibia is acquired with a tracking system, whereas the femur head centre (FHC) is being kept fixed, and the positions and orientations of the geometrical model are calculated to fit the acquired range of motion best in order to calculate the location of the femur head centre (FHC).

2. Method for localizing the femur head centre (FHC) using only a marker array (TM) attached to the tibia (T), wherein

the knee is considered to be a joint having one, two or more degrees of freedom, and a distance di is calculated so that the lines of movement of a point (FHC) having the distance di from the knee joint (KJ) or from the joint element closest to the femur head centre (FHC) in the kinematical chain modelling the knee joint coincide in a single point which is considered to be the femur head centre (FHC).

3. Method for localizing the femur head centre (FHC) according to claim 1 or 2, wherein the tibia (T) is brought to a position which restricts at least one degree of movement of the knee joint (KJ) so that the knee joint (KJ) has basically only a single degree of freedom and the knee is moved by moving the femur (F) and/or the tibia (T).

4. Method according to one of the preceding claims, wherein the knee is navigated using the tibia marker array (TM).

5. Method according to one of the preceding claims, wherein the tibia (T), the femur (F) and/or the knee is moved to a fixed or reproducible determined flexing position to restrict at least one degree of movement of the knee.

6. Method according to one of the preceding claims, wherein the position of the knee joint (KJ) or of the joint elements of the knee joint (KJ) relative to the tibia marker array (TM) is determined.

7. Computer program, which, when loaded in or running on a computer, performs the method of one of the preceding claims.

8. Program storage medium or computer program product comprising the program of the preceding claim.

9. Apparatus for localizing the femur head centre (FHC) using a tibia marker array (TM) connected to the tibia (T), comprising a camera (C) for localizing the tibia marker array (TM), a computer (PC) connected to the camera (C) to obtain the positional data of the tibia marker array (TM) from the camera images of the tibia marker array (TM) and a database (Data) storing a kinematic model of the knee joint (KJ) having at least one or two degrees of freedom, which database (Data) is connected to the computer (PC) which calculates a distance di so that the lines of movement of a point (FHC) having a distance di from the knee joint (KJ) or from the joint element closest to the femur head centre (FHC) in the kinematical chain modelling the knee joint coincide in a single point which is considered to be the femur head centre (FHC).

Tibia-only Procedure

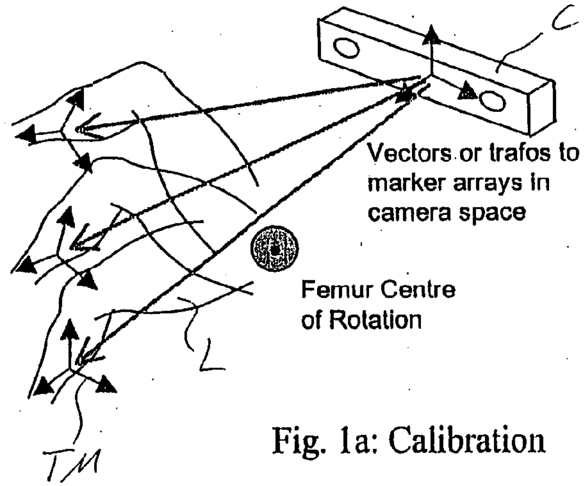


Fig. 1a: Calibration

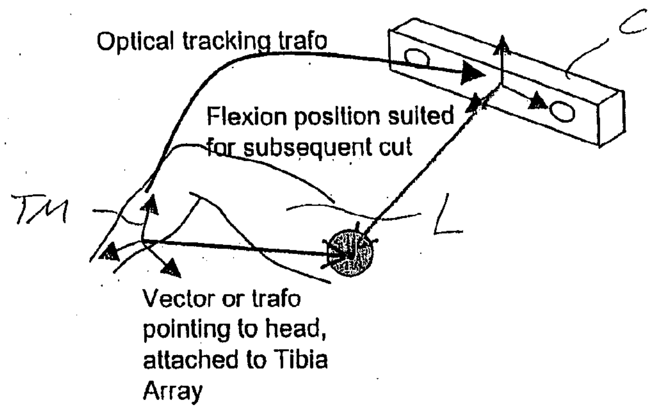


Fig. 1b: Attachment

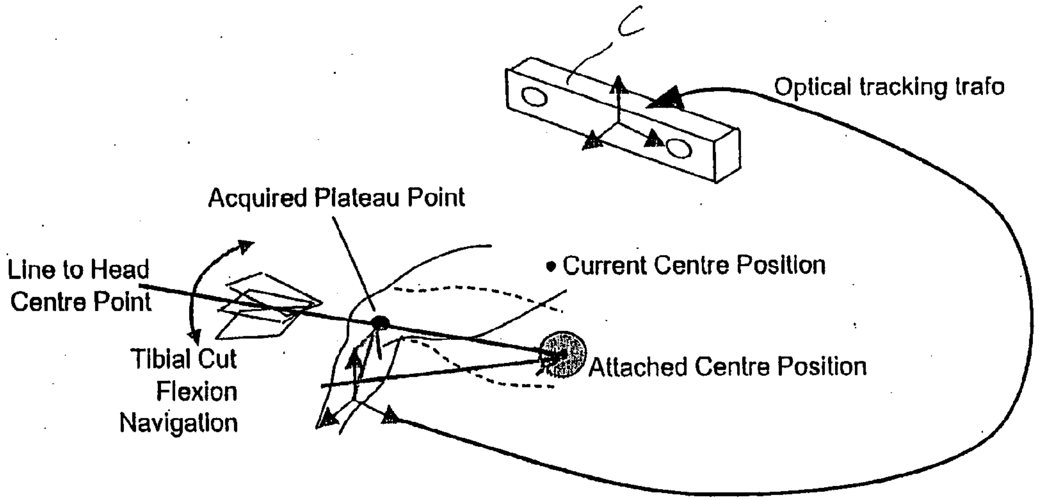


Fig 1c: Tibia Navigation

Femur-too Procedure

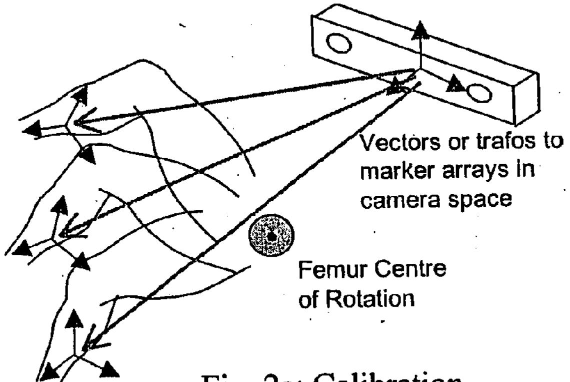


Fig. 2a: Calibration

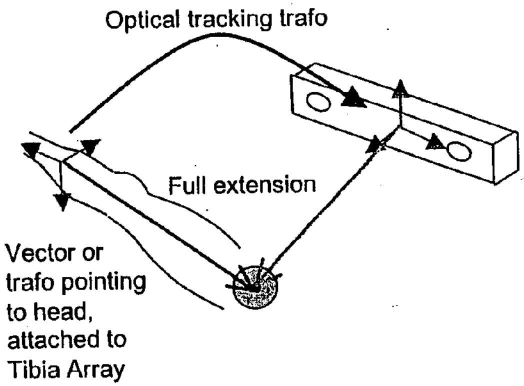


Fig. 2b: Attachment

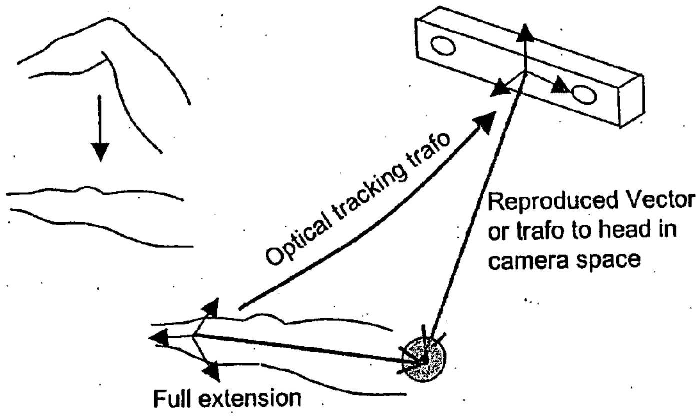


Fig. 2c: Reproduction after movement

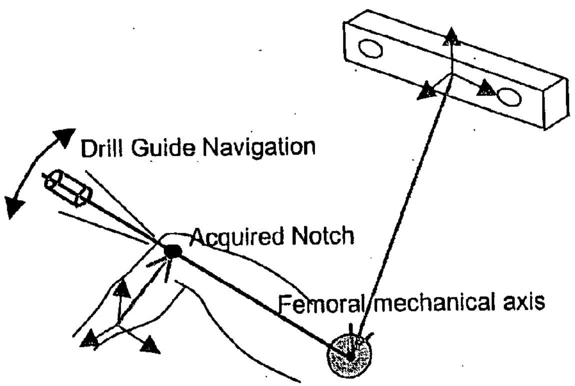


Fig 2d: Femur Navigation

Femur Head Centre Calculation

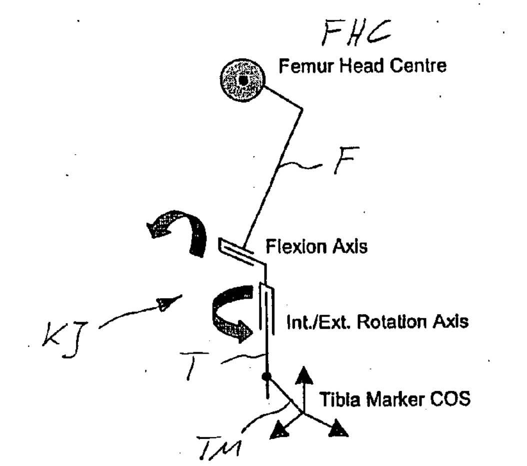


Fig. 3a: Simple Knee model

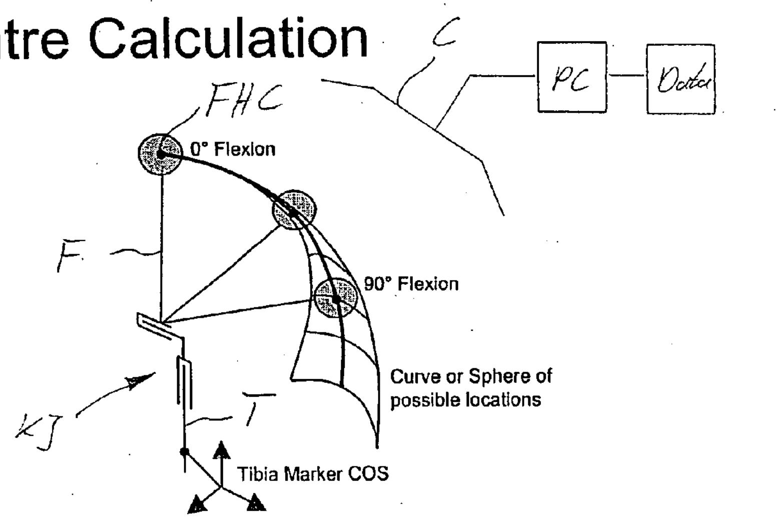


Fig. 3b: Possible centre locations

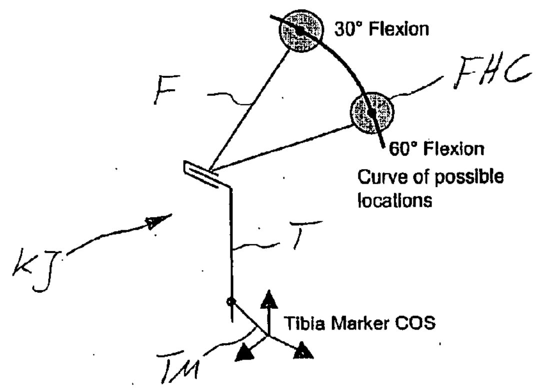


Fig. 3c: Simplification for external rotation

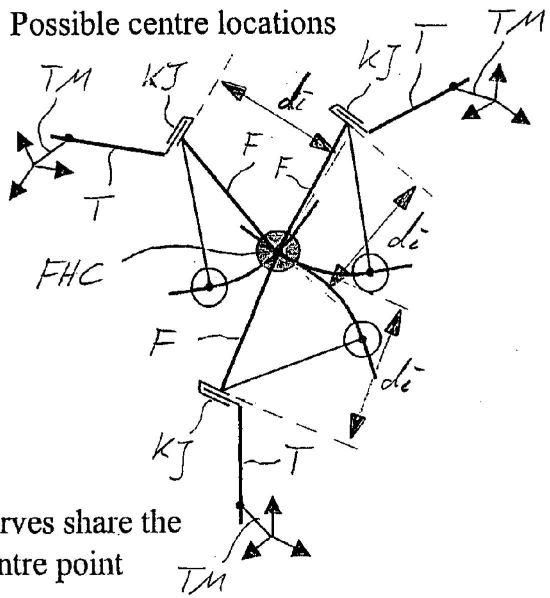


Fig. 3d: Curves share the real centre point

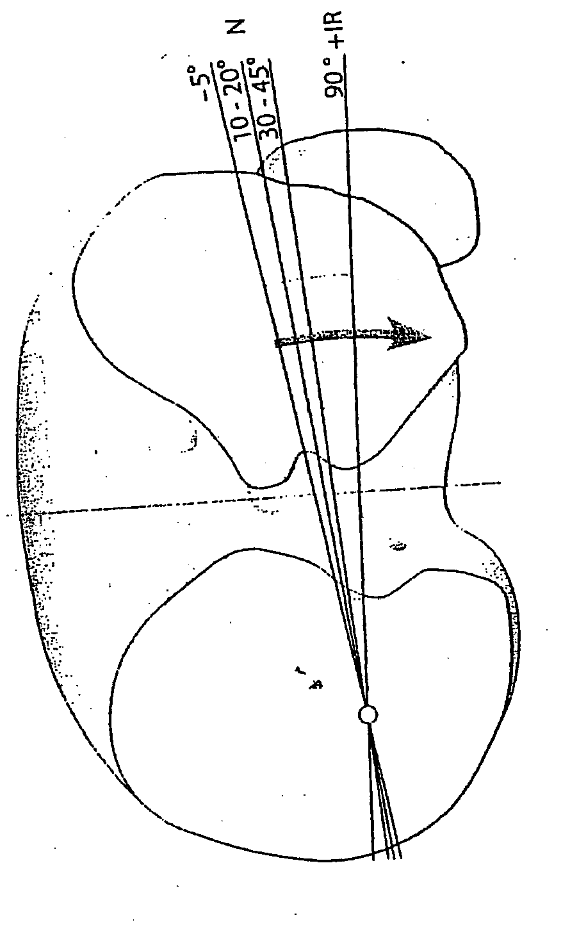
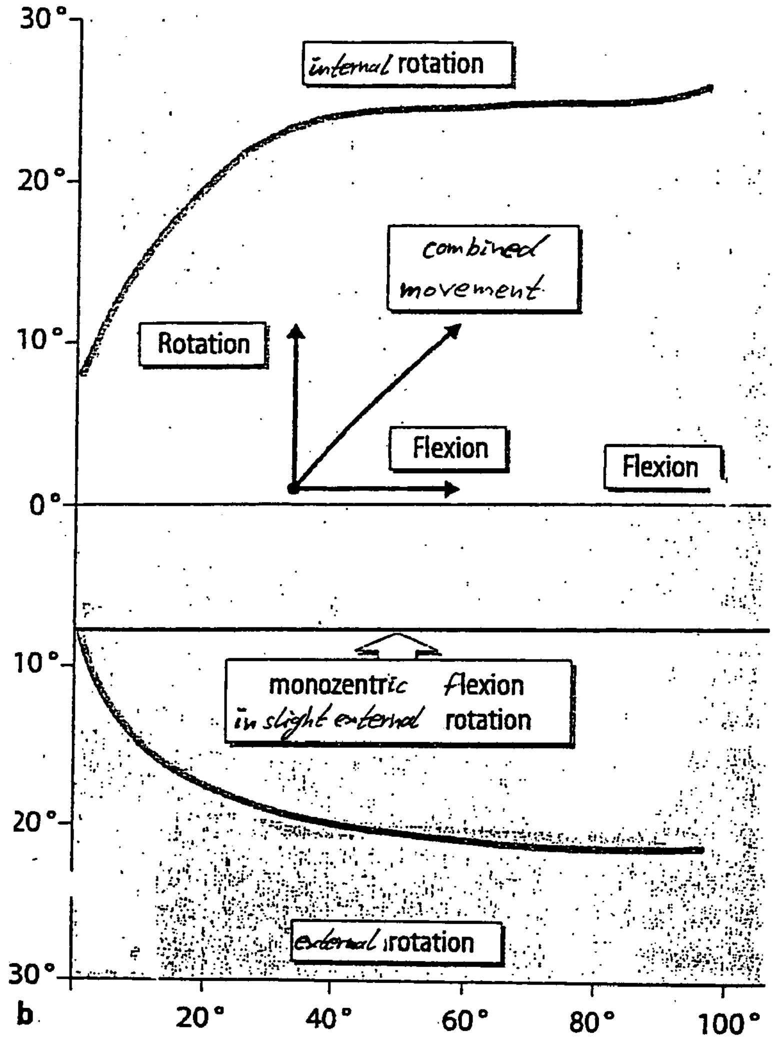
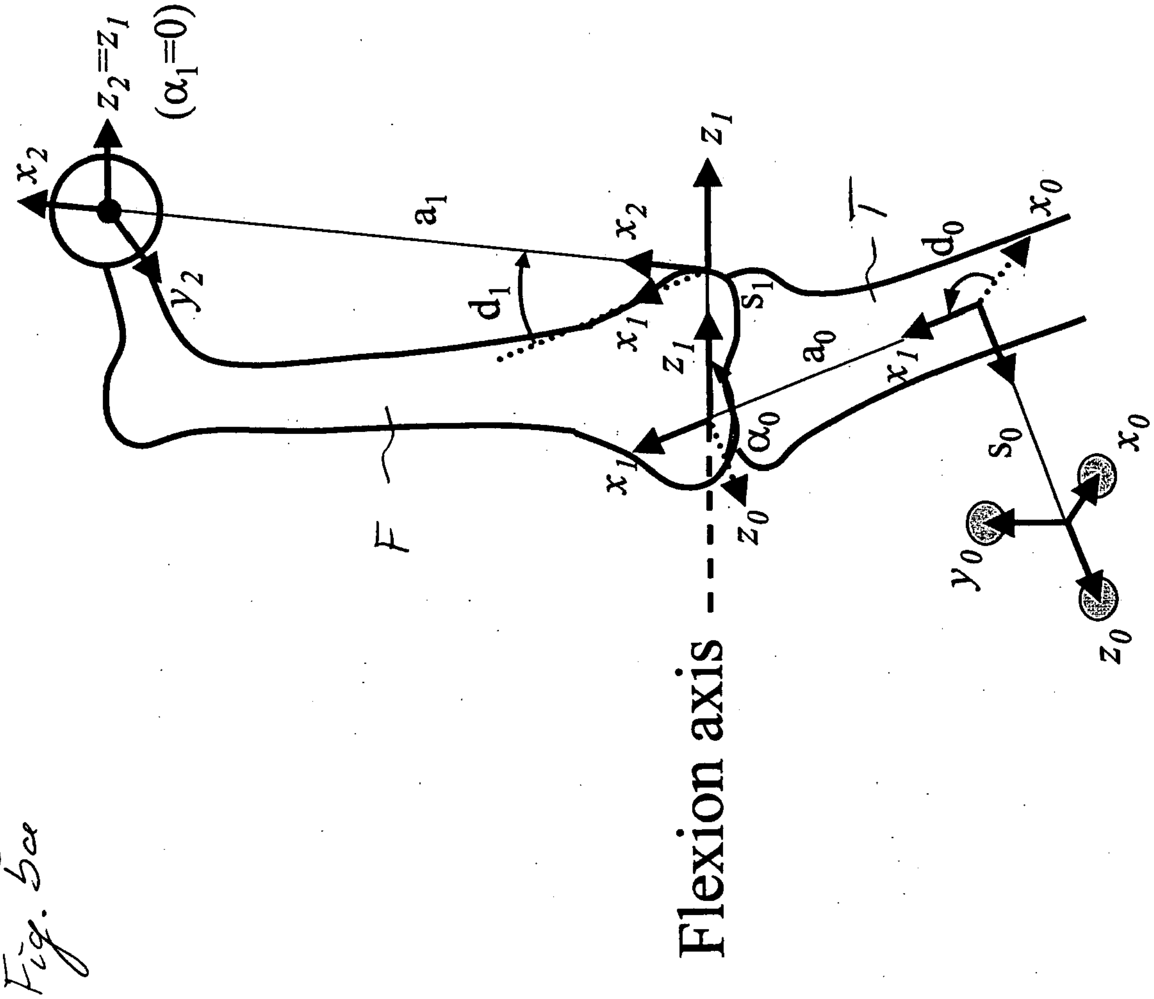


Fig. 4a

Fig. 4b


30°
internal rotation
20°
combined movement
10°
Rotation
Flexion
Flexion
0°
10°
monozentric flexion
in slight external rotation
20°
external rotation
30°
b
20°
40°
60°
80°
100°



Flexion axis
$z_2=z_1$
$(\alpha_1=0)$
x_2
y_2
a_1
d_1
x_1
z_1
s_1
a_0
α_0
z_0
d_0
x_0
s_0
y_0
F
T

Fig. 5a

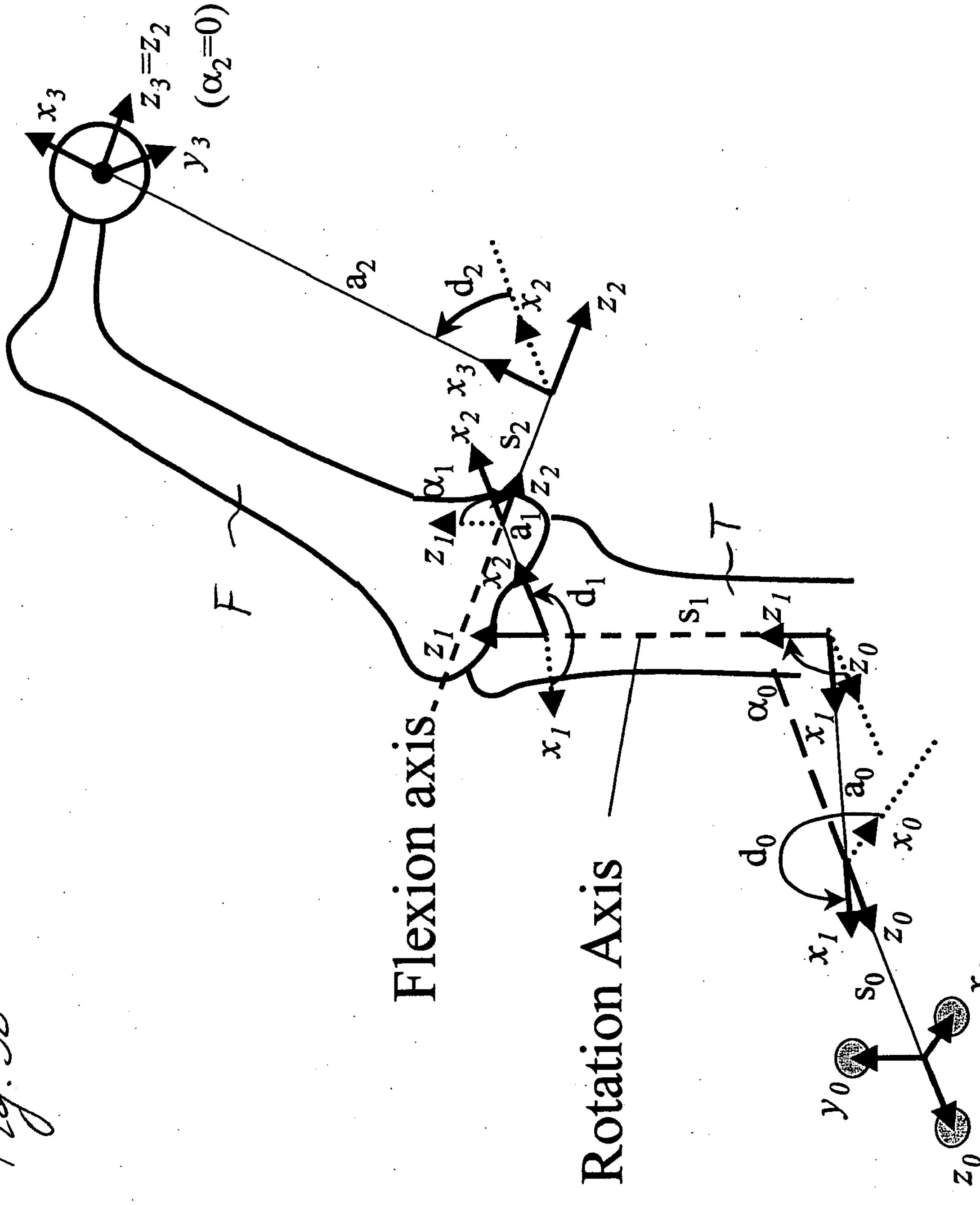

Flexion axis
Rotation Axis
F
T
$z_3=z_2$ $(\alpha_2=0)$
a_2
d_2
d_1
d_0
s_0
s_1
s_2
a_0
a_1
α_0
α_1

Fig. 5b

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 00 0385

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	WO 2005/053559 A (SMITH & NEPHEW, INC; MC COMBS, DANIEL) 16 June 2005 (2005-06-16) * page 14, line 30 - page 15, line 3 * * page 10, line 22 - line 26 * * page 16, paragraph 2 * -----	9 1-8	INV. A61B19/00
			TECHNICAL FIELDS SEARCHED (IPC)
			A61B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	11 May 2006	Hamann, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

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11-05-2006

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2005053559 A	16-06-2005	NONE	

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